CLAIMS

I claim:

1. A downhole measurement tool, comprising:

a substantially cylindrical tool body having a cylindrical axis;

at least one acoustic sensor deployed on the tool body, the acoustic sensor including a piezo-composite transducer element with anterior and posterior faces, the piezo-composite transducer in electrical communication with an electronic control module via conductive electrodes disposed on each of said faces; and

the piezo-composite transducer element including regions of piezoelectric material deployed in a matrix of a substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension.

2. The downhole tool of claim 1, wherein the piezoelectric material is selected from the group consisting of lead zirconate titanates and lead metaniobates.

3. The downhole tool of claim 1, wherein the piezoelectric material has a Curie temperature greater than or equal to about 250 degrees C.

4. The downhole tool of claim 1, wherein the piezoelectric material has a coupling coefficient of greater than or equal to about 0.3.

5. The downhole tool of claim 1, wherein the non piezoelectric material is a polymeric material.

6. The downhole tool of claim 5, wherein the polymeric material is an epoxy resin.

7. The downhole tool of claim 5, wherein the polymeric material has a coefficient of thermal expansion less than about 100 parts per million per degree C.

8. The downhole tool of claim 5, wherein the polymeric material has a glass transition temperature of greater than about 250 degrees C.

9. The downhole tool of claim 1, wherein the regions of piezoelectric material comprise a periodic array of spaced piezoelectric material posts.

10. The downhole tool of claim 9, wherein the piezo-composite transducer element is a product of the process comprising:

providing a piezo-ceramic disk having first and second faces;

cutting a first set and a second set of grooves in the first face, the grooves in the first set being substantially orthogonal to the grooves in the second set, wherein removal of piezo-ceramic material in said groove cutting is operative to shape the piezoelectric material posts;

casting the non piezoelectric material into the grooves to form, in combination with the piezo-ceramic disc, a specimen of piezo-composite material having first and second faces corresponding substantially to those of the piezo-ceramic disk;

polishing the specimen to a predetermined thickness; and

disposing conductive electrodes on each of the first and second faces of the specimen.

11. The downhole tool of claim 1, wherein the piezo-composite transducer element comprises a laminate including alternating layers of the piezoelectric material and the non piezoelectric material.

12. The downhole tool of claim 1, wherein the piezo-composite transducer element includes alternating concentric rings of the piezoelectric material and the non piezoelectric material disposed about a central element of the piezoelectric material.

13. The downhole tool of claim 12, comprising from about 2 to about 8 rings of the piezoelectric material.

14. The downhole tool of claim 12, wherein each of the rings of the piezoelectric material has a predetermined radial thickness selected to decrease with increasing distance from the central element.

15. The downhole tool of claim 14, wherein the radial thickness of the rings of piezoelectric material is selected to decrease according a mathematical function selected from the group consisting of Bessel functions and Gaussian functions.

16. The downhole tool of claim 12, wherein the piezo-composite transducer element comprises a periphery and a plurality of axial slots disposed around the periphery.

17. The downhole tool of claim 12, wherein the piezo-composite transducer element comprises a periphery and first, second, third, and fourth axial slots disposed substantially equidistantly around the periphery.

18. The downhole tool of claim 12, wherein the piezo-composite transducer element is a product of the process comprising:

providing a piezo-ceramic slurry;

casting the piezo-ceramic slurry in a reverse mold to form the concentric rings of piezoelectric material about the central element;

casting the non piezoelectric material in open spaces between the concentric rings of piezoelectric material to form, in combination with the concentric rings of piezoelectric material, a specimen of piezo-composite material having first and second faces;

polishing the specimen to a predetermined thickness; and

disposing conductive electrodes on each of the first and second faces of the specimen.

19. The downhole tool of claim 1, wherein the piezo-composite transducer element includes first and second separate piezoelectric elements, the first piezoelectric element serving as a transmitter, the second piezoelectric element serving as a receiver.

20. The downhole tool of claim 19, wherein the first and second piezoelectric elements are substantially isolated electromechanically from one another by a non piezoelectric material.

21. The downhole tool of claim 19, wherein the first piezoelectric element includes a lead zirconate titanate piezoelectric material and the second piezoelectric element includes a lead metaniobate piezoelectric material.

22. The downhole tool of claim 1, wherein the conductive electrodes comprise gold.

23. The downhole tool of claim 1, in which the piezo-composite transducer element is deployed in a housing, and further comprising a pressure equalization layer disposed on an interior surface of the housing.

24. The downhole tool of claim 23, wherein the pressure equalization layer includes silicone oil.

25. The downhole tool of claim 1, in which the at least one acoustic sensor comprises first, second, and third acoustic sensors, each acoustic sensor including corresponding first, second, and third piezo-composite transducer elements.

26. The downhole tool of claim 25, in which the tool body has a periphery, and wherein the first, second, and third acoustic sensors are disposed substantially equidistantly about the periphery of the tool body.

27. The downhole tool of claim 1, wherein the electronic control module is deployed in the tool body.

28. The downhole tool of claim 1, in which the tool body is couplable with a drill string.

29. The downhole tool of claim 1, in which the downhole tool is selected from the group consisting of a logging while drilling tool and a measurement while drilling tool.

30. The downhole tool of claim 1, wherein the at least one acoustic sensor further comprises a laminate including a backing layer deployed nearer to the cylindrical axis from the piezo-composite transducer.

31. The downhole tool of claim 1, wherein the at least one acoustic sensor further comprises a laminate including at least one matching layer deployed further away from the cylindrical axis than the piezo-composite transducer.

32. The downhole tool of claim 1, wherein the at least one acoustic sensor further comprises a laminate including the piezo-composite transducer and a barrier layer,

the barrier layer deployed on an outermost surface of the laminate furthest away from the cylindrical axis.

33. An acoustic sensor, comprising:

a laminate including a piezo-composite transducer element having first and second faces, the laminate further including a composite backing layer deployed on the first face of the piezo-composite transducer element;

the piezo-composite transducer element including regions of piezoelectric material deployed in a matrix of a substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension;

the piezo-composite transducer element including conductive electrodes disposed on the first and second faces thereof; and

the composite backing layer comprising at least one powder material disposed in an elastomeric matrix material.

34. The acoustic sensor of claim 33, wherein the at least one powder material comprises at least one tungsten powder.

35. The acoustic sensor of claim 34, wherein the at least one powder material comprises first and second tungsten powders, the first tungsten powder having an average particle size greater than that of the second tungsten powder.

36. The acoustic sensor of claim 35, wherein:

the first tungsten powder has average particle size ranging from about 2 to about 4 microns; and

the second tungsten powder has an average particle size ranging from about 10 to about 18 microns.

37. The acoustic sensor of claim 33, wherein the elastomeric material comprises a fluoroelastomer material.

38. The acoustic sensor of claim 37, wherein the fluoroelastomer material comprises about 66 atomic percent fluorine.

39. The acoustic sensor of claim 37, wherein the fluoroelastomer material comprises about 68 atomic percent fluorine.

40. The acoustic sensor of claim 37, wherein the fluoroelastomer material comprises about 70 atomic percent fluorine.

41. The acoustic sensor of claim 37, wherein the fluoroelastomer material includes a copolymer of vinylidene fluoride and hexafluoropropylene.

42. The acoustic sensor of claim 37, wherein the composite backing layer further comprises at least one acid accepter selected from the group consisting of magnesium oxide, calcium hydroxide, litharge, zinc oxide, dyphos, and calcium oxide.

43. The acoustic sensor of claim 37, wherein the composite backing layer further comprises at least one carbon black filler.

44. The acoustic sensor of claim 37, wherein the composite backing layer further comprises at least one mineral filler selected from the group consisting of barium sulfate, calcium silicate, titanium dioxide, calcium carbonate, diatomaceous silica, and iron oxide.

45. The acoustic sensor of claim 37, wherein the composite backing layer is a product of the process comprising:

dissolving the fluoroelastomer material in a liquid solvent;

mixing one or more tungsten powders into the solvent;

substantially evaporating the solvent to form a specimen of fluoroelastomer composite material; and

forming the composite backing layer by hot pressing the specimen into a pellet shape.

46. The acoustic sensor of claim 33, further comprising an additional backing layer disposed adjacent the composite backing layer, the additional backing layer having a negative coefficient of thermal expansion.

47. The acoustic sensor of claim 46, wherein the additional backing layer comprises a glass ceramic material.

48. The acoustic sensor of claim 46, wherein the composite backing layer is interposed between the piezo-composite transducer element and the additional backing layer.

49. The acoustic sensor of claim 33, wherein:

the regions of piezoelectric material include a periodic array of spaced piezoelectric material posts;

the piezoelectric material is selected from the group consisting of lead zirconate titanates and lead metaniobates and has a Curie temperature greater than or equal to about 250 degrees C; and

the non piezoelectric material includes an epoxy resin.

50. The acoustic sensor of claim 33, wherein the laminate further comprises one or more matching layers deployed proximate the second face of the piezo-composite transducer element.

51. An acoustic sensor, comprising:

a laminate including a piezo-composite transducer element having first and second faces, the laminate further including a matching layer assembly deployed on the second face of the piezo-composite transducer element;

the piezo-composite transducer element including regions of piezoelectric material deployed in a matrix of a substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension;

the piezo-composite transducer element including conductive electrodes disposed on the first and second faces thereof; and

the matching layer assembly including at least one matching layer and at least one barrier layer, the barrier layer being formed from a metallic material, the at least one matching layer being deployed between the piezo-composite transducer element and the barrier layer.

52 The acoustic sensor of claim 51, wherein the at least one matching layer comprises first and second matching layers, the first matching layer being deployed between the piezo-composite transducer element and the second matching layer.

53. The acoustic sensor of claim 52, wherein the first matching layer has an acoustic impedance in the range from about 8 to about 14 MRayl.

54. The acoustic sensor of claim 52, wherein the first matching layer comprises an epoxy resin.

55. The acoustic sensor of claim 54, wherein the first matching layer comprises a composite mixture of the epoxy resin and a ceramic material.

56. The acoustic sensor of claim 52, wherein the first matching layer comprises a ceramic material.

57. The acoustic sensor of claim 52, wherein the second matching layer has an acoustic impedance in the range from about 3 to about 7 MRayl.

58. The acoustic sensor of claim 52, wherein the second matching layer comprises an epoxy resin.

59. The acoustic sensor of claim 52, wherein the second matching layer comprises a composite mixture of an epoxy resin and a ceramic material.

60. The acoustic sensor of claim 52, wherein the first matching layer and the second matching layer are formed from a single glass ceramic work piece.

61. The acoustic sensor of claim 60, wherein the glass ceramic work piece has a plurality of openings formed in one face thereof, the openings being filled with an epoxy resin.

62. The acoustic sensor of claim 61, wherein the openings are selected from the group consisting of holes, cuts, grooves, dimples, and indentations.

63. The acoustic sensor of claim 61, wherein the plurality of openings comprise from about 40 to about 80 volume percent of the second matching layer.

64. The acoustic sensor of claim 51, wherein the at least one matching layer comprises a single matching layer having an acoustic impedance that decreases from a relatively higher value at a first face of the matching layer to a relatively lower value at a second face of the matching layer.

65. The acoustic sensor of claim 64, wherein the single matching layer comprises a glass ceramic disk having a plurality of openings formed in one face of the matching layer, the openings being filled with an epoxy resin.

66. The acoustic sensor of claim 65, wherein the openings are tapered such that an area ratio of the epoxy resin to the glass ceramic increases from the first face to the second face.

67. The acoustic sensor of claim 51, wherein the metallic material is selected from the group consisting of stainless steel and titanium.

68. The acoustic sensor of claim 51, wherein the metallic material comprises titanium.

69. The acoustic sensor of claim 51, wherein the barrier layer has an acoustic impedance less than about 10 MRayl.

70. The acoustic sensor of claim 51, wherein the barrier layer is corrugated.

71. The acoustic sensor of claim 70, wherein said corrugated barrier layer is formed by a metal stamping process.

72. The acoustic sensor of claim 51, wherein the barrier layer comprises a composite material including a metallic work piece including opposing faces, the work piece having a plurality of openings formed in one of the faces thereof, the plurality of openings being filled with an epoxy resin.

73. The acoustic sensor of claim 72, wherein the openings are selected from the group consisting of holes, cuts, and grooves.

74. The acoustic sensor of claim 72, wherein the openings comprise a plurality of concentric grooves.

75. The acoustic sensor of claim 51, wherein the barrier layer is welded to a sensor housing.

76. The acoustic sensor of claim 51, wherein:

the regions of piezoelectric material include a periodic array of spaced piezoelectric material posts;

the piezoelectric material is selected from the group consisting of lead zirconate titanates and lead metaniobates and has a Curie temperature greater than or equal to about 250 degrees C; and

the non piezoelectric material includes an epoxy resin.

77. The acoustic sensor of claim 60, further comprising a backing layer deployed proximate the first face of the piezo-composite transducer element.

78. An acoustic sensor, comprising:

a laminate including a piezo-composite transducer element having first and second faces, the laminate further including a composite backing layer deployed on the first face of the piezo-composite transducer element and a matching layer assembly deployed on the second face of the piezo-composite transducer assembly;

a piezo-composite transducer element including regions of piezoelectric material disposed in a matrix of a substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension;

the piezo-composite transducer element including conductive electrodes disposed on the first and second faces thereof;

the composite backing layer including at least one powder material disposed in a fluoroelastomer matrix material; and

the matching layer assembly including at least one matching layer and a barrier layer, the barrier layer including a metallic material, the at least one matching layer being deployed between the piezo-composite transducer element and the barrier layer.

79. The acoustic sensor of claim 78, wherein:

the regions of piezoelectric material include a periodic array of spaced piezoelectric posts;

the piezoelectric material is selected from the group consisting of lead zirconate titanates and lead metaniobates and has a Curie temperature greater than or equal to about 250 degrees C; and

the non piezoelectric material includes an epoxy resin.

80. The acoustic sensor of claim 78, wherein:

the powder material includes a tungsten powder;

the matching layer assembly includes first and second matching layers, the first matching layer being deployed between the piezo-composite transducer element and the second matching layer, the first matching layering having an acoustic impedance in the range from about 8 to about 15 MRayl, and the second matching layer having an acoustic impedance in the range from about 3 to about 7 MRayl; and

the barrier layer includes corrugated titanium.

81. An acoustic sensor, comprising:

a piezo-composite transducer element including regions of piezoelectric material deployed in a matrix of a substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension;

the piezoelectric material having a Curie temperature greater than or equal to about 250 degrees C;

the piezo-composite transducer element including conductive electrodes disposed on first and second faces thereof; and

the acoustic sensor being configured for use in a downhole measurement tool.

82. A method for fabricating a downhole measurement tool, the method comprising:

(a) providing a substantially cylindrical tool body having an electronic control module, the tool body being couplable with a drill string;

(b) providing at least one acoustic sensor including a piezo-composite transducer element with anterior and posterior faces, the piezo-composite transducer element including regions of piezoelectric material deployed in a matrix of substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension; the piezo-composite transducer element further including conductive electrodes disposed on each of said faces;

(c) deploying the at least one acoustic sensor on the tool body in electrical communication with the electronic control module via said conductive electrodes, the at least one acoustic sensor operable to transmit and receive acoustic signals in a borehole.

83. A method for fabricating an acoustic sensor, the method comprising:

(a) forming a piezo-composite transducer element having first and second faces and including regions of piezoelectric material deployed in a matrix of substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension;

(b) disposing conductive electrodes on the first and second faces of the piezo-composite transducer element;

(c) forming a composite backing layer having at least one powder material disposed in an elastomeric matrix material; and

(d) deploying the composite backing layer on the first face of the piezo-composite transducer element, the composite backing layer operable to substantially attenuate acoustic energy back reflected into the acoustic sensor.

84. A method for fabricating an acoustic sensor, the method comprising:

(a) forming a piezo-composite transducer element having first and second faces and including regions of piezoelectric material deployed in a matrix of substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension;

(b) disposing conductive electrodes on the first and second faces of the piezo-composite transducer element;

(c) forming at least at least one matching layer and a barrier layer, the barrier layer including a metallic material;

(d) deploying the at least one matching layer on the second face of the piezo-composite transducer element; and

(e) deploying the barrier layer proximate the at least one matching layer, the at least one matching layer being deployed between the piezo-composite transducer element and the at least one barrier layer.

85. A method for fabricating an acoustic sensor, the method comprising:

(a) forming a piezo-composite transducer element having first and second faces and including regions of piezoelectric material deployed in a matrix of substantially non piezoelectric material, the regions extending through a thickness of the transducer element in at least one dimension;

(b) disposing conductive electrodes on the first and second faces of the piezo-composite transducer element;

(c) forming a composite backing layer having at least one powder material disposed in an elastomeric matrix material;

(d) forming at least at least one matching layer and a barrier layer, the barrier layer including a metallic material;

(e) deploying the composite backing layer on the first face of the piezo-composite transducer element;

(f) deploying the at least one matching layer on the second face of the piezo-composite transducer element; and

(g) deploying the barrier layer proximate the at least one matching layer, the at least one matching layer being deployed between the piezo-composite transducer element and the at least one barrier layer.